Applying Neuroscience Concepts to Enhance Learning in an Online Project-Based Learning Centered Course

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ABSTRACT

This case study presents our findings regarding a Project-Based Learning Course, where we applied neuroscience concepts to make the learning experience more effective. The course, which followed a combination of project-based learning and flipped classroom approaches, was delivered during the first semester of 2020, to 20 graduate students of the Faculty of Education of the University of Sao Paulo, Brazil. We explain the course design, curriculum, and online components. We collected data from course questionnaires and analyzed them qualitatively. We found that the course fostered long-lasting learning, by allowing the students to connect theory and practice, by providing knowledge-sharing opportunities and by promoting the retrieval of the content learned. We also found that course design allowed continuous improvement of course, learning environment and activities, that also enhanced the learning experience. Our findings also suggested that the usage of flipped-classroom concepts improves the efficacy of the online meetings. Finally, comic strips' usage brought humor to class, helped the students fix content, and contributed to reducing the stress that the students were facing.

DESCRIPTION OF THE CONTEXT

In this case study, we present the lessons learned about the application of neuroscience concepts in a course developed in a distance-learning environment. The course, entitled 'Project-Based Learning' was delivered to 20 graduate students from the Faculty of Education from the University Sao Paulo. The graduate students were teachers from several public and private schools in Sao Paulo. The course followed a project-based

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learning approach. The seven-week long course began in the middle of May and ended by the beginning of July of 2020. The course aimed to teach the students project-based learning concepts in conjunction with neuroscience concepts. The course was delivered during the Covid19 pandemic; therefore, it had several constraints to its implementation. The first constraint was the students' availability. Since all the students were also teachers, almost all of them were deeply involved in restructuring their teaching courses. The restructuring process required a huge workload: consequently, they had limited time to perform graduate activities. The second constraint was the students' psychological conditions: all of them were confined in their houses with their families in a stressful condition for a number of them. To make things worse, many of the students had no previous experience designing and delivering online courses and had to do it rapidly. Therefore, the confinement and the job's challenges were causing a stressful situation.

However, this negative context also brought benefits to our course. Since our first online meeting, it became clear to us that the students saw our course as the place where they could find answers to the new problems that they were facing. They were deeply interested in learning project-based learning concepts to apply them in the online courses they were delivering. They were also paying attention to the way we were conducting our course to replicate our practices in their courses.

In this case study, we began with a theoretical review of the neural mechanisms of the learning and two active learning approaches (project-based learning and flipped classroom) that could be used to improve learning. We defined our research questions and described the context of the experiment that was developed to investigate possible answers to these questions. After that, we described our research method and the way we used to gather and analyze data. In sequence, we discussed the results, performing qualitative systemic analysis. Finally, we presented the findings and the limitations of our research.

THEORETICAL FRAMEWORK

Neuroscience studies (Bransford, Brown, & Cocking, 2000; Hebb, 1949) revealed that the learning process leads to the creation of connections between several neural networks of different brain areas (Morris, Kandel, & Squire, 1988). Neurons connect each other by means of gates that are functionally modulated by neurotransmitters in the so-called synaptic junctions (Beale & Jackson, 1990). The long-lasting learning occurs when the connections between the neurons are strong and the networks are wide (Fregni, 2019; Sousa, 2010). Studies also revealed that images (such as comics) facilitate the students to understand abstract concepts and to make connections with real-world situations (Bolton-Gary, 2012).

Therefore, in order to foster long-lasting learning, teachers should stimulate the students to connect the new concepts with the concepts the students already know (Deshler et al., 2001; Fregni, 2019; Sousa, 2010). In doing so, the students create new neural network paths and thus create a more distributed neural network that facilitates long-lasting learning (Draganski et al., 2004).

However, synaptic strengthening may weaken over time. To avoid that, one should retrieve the information periodically (Karpicke, Butler, & Roediger III, 2009). Based on this concept, teachers should also provide opportunities for retrieving the concepts taught (Karpicke & Roediger, 2008) and allow metacognition to strengthen the connections between the neural networks.

Another important concept to enhance learning is to increase attention. Neuroscience researchers show that our brain filters out constant and repetitive information (Fregni, 2019): therefore, in order to foster learning, the teacher should change the type and the duration of the stimulus (Sousa, 2010). Finally, two other important factors can interfere with learning: stress and anxiety (Christianson, 1992). However, there is an important dose relationship for these factors. Too little and too much stress decrease learning (Christianson, 1992, Fregni, 2019), while moderate stress may be beneficial if related to the learning context.

Project-based learning (thereafter PBL) is an educational approach that can be used to foster long-lasting learning. It is a student-centered approach rather than teacher-centered. In a typical PBL-centered course, the students work collaboratively to find answers to a question, or to solve a real-life problem (Bender, 2012). During the project the students are challenged to work collaboratively, researching ways of finding solution to the proposed challenge (Savery, 2015). The project is used not only to teach academic content but also to develop critical thinking skills (Bell, 2010). The course is managed by the teacher as project, with well-defined milestones and deliverables (van Rooij, 2009).

Project-based learning centered courses foster students' interaction and class discussion (Pollock, Hamann, & Wilson, 2011). Also, it allows the teacher to provide feedback to the students (Larmer & Mergendoller, 2010). It also stimulates the students to ask questions and promote in-deep inquiry (Larmer, Mergendoller, & Boss, 2015). A well-conducted PBL course allows the students to reflect on the learning process itself (Blumenfeld et al., 1991). More than that, PBL allows students to learn by doing (Bender, 2012). During PBL centered courses, the teacher may change the type and duration of the stimulus, fostering activities that enhance motivation (Markham, 2003). Therefore, the PBL approach may provide opportunities to the students to connect the new knowledge with previous knowledge, may give occasions on retrieval and reflection, and may also

favor metacognition processes, the main issues that neuroscientists point that improve the learning experience.

Project-based learning may work better if the teacher challenges the students to study the class content previous to the class (Shih & Tsai, 2017). The strategy of providing means to the student to study the learning material previously to the class and use the class time to clarify their doubts is known as the flipped classroom (Bergman & Sams, 2012). The use of flipped classroom strategy may bring several benefits (Smith, 2017), such as improving student´s motivation and interest (Zainuddin & Halili, 2016), enhance the communication between the students and between the teacher and students (El Miedany, 2019), facilitate the group work activities and collaboration (Flumerfelt & Green, 2013), foster critical reflection (Roehl, Reddy, & Shannon, 2013), allows self-paced learning (Weng, 2015), facilitate differentiating instruction (Siegle, 2014) therefore enhancing the students' learning.

The neuro-scientific principles of teaching and learning are complementary and closely connected with the well stablished socio-constructivist principles of PBL (Savin-Baden & Major, 2004), which postulate that a student create knowledge based on his/her previous knowledge and experiences (Hendry et al.,1999) and by exchanging experiences with their peers (Richardson, 2003; Savery & Duffy, 1995).

The following figure (Figure 1) may help to have a better understanding that the comprehension of the mechanisms of neural learning can help the teacher to choose the educational approaches to foster learning. In this case study, we explore the application of only two approaches (project-based learning and flipped-classroom).
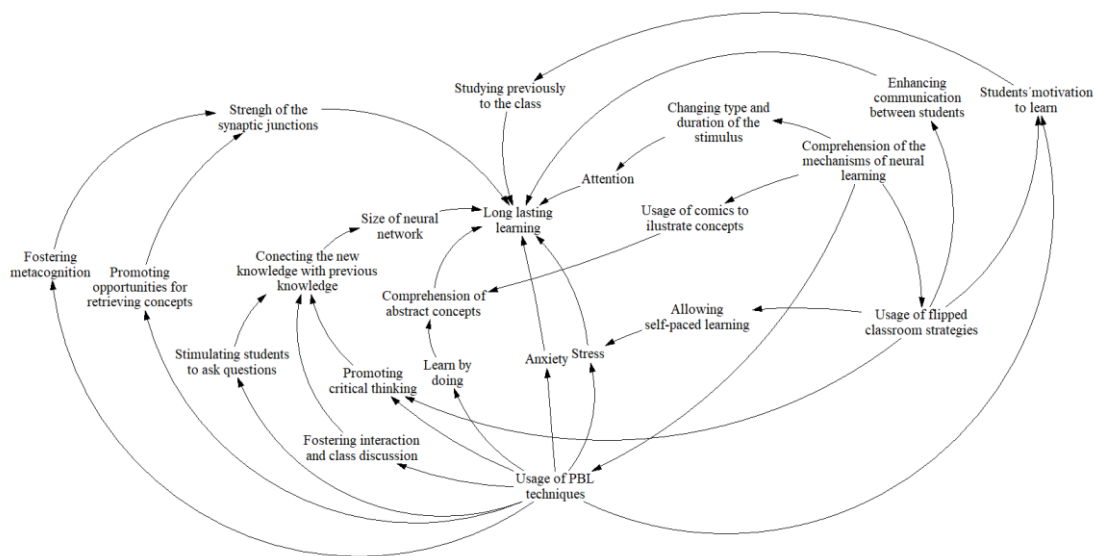

Figure 1. The comprehension of neural mechanisms of learning helps to choose the educational approach.

The 2020 Covid-19 pandemic brought several challenges to the students and the teachers (Toquero, 2020). The teachers were challenged to transform rapidly traditional face-to-face courses into online courses (Bao, 2020). They had to learn not only how to choose and use online learning platforms and tools, but also how to provide a meaningful learning experience (Reimers & Schleicher, 2020). The students were challenged to learn under stress in living conditions far from ideal (Cao et al., 2020).

Although scholars point out that PBL can also be applied in distance learning context (Arantes do Amaral et al, 2018), it seems that there is still a lack of information about the application of PBL programs in the context of Covid-19 pandemic online teaching. Our aim in this article is to understand how to maximize the learning experience in an online PBL centered course in the COVID-19 context. We also aimed to use neuroscience findings to discuss our results based on our course experience.

CONCRETE IMPLEMENTATION

Our course followed a PBL approach: it was designed in order to provide opportunities to the students to learn project-based learning concepts and experience them while accomplishing practical projects. The course was also designed to maximize learning by making use of neuroscience strategies to allow the students to connect the content they were learning with their previous knowledge and experiences (Appendix 1). The course was designed to provide the maximum of critical reflection and metacognition opportunities: the student would learn concepts, apply what they learned in projects, reflect on the learning process during the program and share insights with their peers. More than that, the course was designed using the flipped classroom concepts: the students were challenged to study the week material before each class. We designed the course this way to make online meetings more productive.

However, the course was delivered under the Covid-19 pandemic. As discussed previously, the students were under stress and had very limited time to accomplish course projects and interact with other students. Therefore, we decided that the projects would have a simpler scope, and the students would develop the project individually.

The course was developed in seven weeks (Appendix 2). Each week, the students were asked to read articles, watch short-documentaries, and read a chapter from the textbook (Fregni, 2019) and from the comic book (Fregni & Arantes do Amaral, 2020). Every week, the students had an online meeting (approximately two-hours long, on Mondays) with the teacher to discuss the activities accomplished during the week, clarify issues, and discuss the readings and videos and share experiences. After the meeting, the students were asked to answer a questionnaire (Appendix 3). The questionnaire had three

objectives: the first objective was to foster the students' reflection about the week's learning. The second objective was to identify what concepts the students didn't learn well. The third objective was to give the students the opportunity to suggest course improvements.

Every weekend the teacher read all the questions and created a short video providing feedback to the students. In addition to that (based on students' suggestions of course improvement), the teacher made adaptations in the way the course would be conducted in the following week. In doing so, the teacher provided continuous improvement in the way the course was conducted. This also increases the interaction by enhancing motivation.

The students were also required to deliver two small projects, one in week five and another in week six (Appendix 2). The projects were designed to allow the students to experience the challenges involved in PBL courses by doing two simple projects that lead to the creation of short videos. More than that, the projects also aimed to provide metacognition, given the students the opportunity to reflect on their own learning and share their findings with their peers.

In the final week of the course, the teacher asked the student to answer a final questionnaire about the teaching and learning strategies and material used in the course (Appendix 4). The questionnaire also provided two questions about self-assessment. The students' answers were the data used in our reflection.

RESULTS AND REFLECTIONS

The data of the final questionnaire was analyzed qualitatively. We used the language processing method (Shiba, Graham, & Walden, 1993) in order to organize the data in categories of recurrent themes (Bradley, Curry, & Devers, 2007). We proceeded as follows: first, we broke the answers of the students in sentences. Then compiled the similar sentences into categories of similar meaning and created a label for each category. After that, we reassemble the categories into broader clusters. Then created sentences (the recurrent themes) that summarized the mean ideas of each cluster.

In sequence, we performed a qualitative systemic analysis (Arantes do Amaral, 2019; Lalanda-Gonçalves, 2015) of the recurrent themes, using a system dynamics modeling tool, a causal loop diagram (Yearworth &White, 2013). We proceeded as follows: first, we analyzed the interconnection between the ideas expressed by the recurrent themes, representing the key ideas by means of variables and the connections by means of causal links (Senge et al., 2012; Sterman,2010). We identified the reinforcing and balancing feedback loops and connect then, creating a model of the relationships by means of a

causal loop diagram (Figure 2). The causal loop diagram allowed us to understand the systemic structure responsible for the patterns of behavior we observed in our course (Schaffernicht, 2010).

Results

Eight recurrent themes (therefore RT) emerged from the analysis of the students' answers:

RT1: The weekly questionnaires helped the students review and reflected on the course content and organize the ideas, therefore reinforcing the learning.

RT2: The articles were meaningful to the students, since they helped the learning, by providing the necessary theory and practical examples of applications of PBL in different educational contexts.

RT3: The videos were inspiring and interesting. They helped the students make connections between theory and practice, reinforcing the learning by providing the students with real-life practical examples of implementation of PBL. In addition to that, the videos also brought new insights to the students and helped fix the content and motivate them to learn.

RT4: The online meetings helped the students clarify doubts and have a better understanding of the readings/videos. More than that, it promoted knowledge sharing by the exchange of different points of view.

RT5: The comic book brought humor to the course, motivating the students to learn. The comic strips facilitated the learning of the neuroscience concepts; the images helped to consolidate the content and review and summarize the textbook concepts.

RT6: The online forum and the videos created by the students promoted intense knowledge-sharing opportunities. The students' diverse backgrounds brought different perspectives and examples. However, few students suggested that the course's platform chosen (Google Classroom) was not adequate for forum activities.

RT7: The weekly feedback provided by the teacher, by means of a video, helped the course to be improved week by week. More than that, it also promoted knowledge sharing, since the teacher summarized the main issues pointed by the students, clarified the doubts, and commented on the students' suggestions for the course improvement.

RT8: The students acknowledged that they intend to apply all the topics studied, in special PBL, CBL (Community-based learning), critical thinking in the courses that they teach. They also let us know that they intend to apply neuroscience concepts in their teaching activities.

Reflections

So, what did we learn from this course?

Going back to our research question, the data revealed that the teaching approach we followed (asking the students to review the material prior to the online meetings) worked very well. The students used the online meetings to clarify issues, rather than to watch teacher presentation. This finding is aligned with the findings of other scholars (Nam, 2017, Shih & Tsai,2017) that pointed out the efficacy of the use of flipped classroom in project-based learning online courses. The more the students studied before the class, the better the was quality of the online meetings, which led to an increase in the learning experience (Figure 2, Feedback loop 'Fostering pre-class content instruction').

We also learned that the videos, the accomplishment of the projects' activities, the reflection about the teacher's weekly feedback, and the readings helped the students associate the theoretical concepts with real-life experiences. These activities connected theory with practice, therefore fostering long-lasting learning (Figure 2, Feedback loop 'Fostering long-lasting learning').

In addition to that, the students' participation in the online forum helped the students learn with each other. Also, the video feedback from the teacher promoted an intense knowledge sharing and improved the connection between theory and practice (Figure 2, Feedback loop 'Promoting knowledge sharing').

The weekly questionnaires helped the students reflect on learning, retrieve the concepts studied previously, and strengthen the connections made, therefore contributing to the long-lasting learning (Figure 2, Feedback loop 'Providing retrieval opportunities'). The weekly questionnaires also helped the teacher to make quick corrections in the way the course was delivered, leading to improvements in the teaching and learning practices, therefore also favoring learning (Figure 2, Feedback loop 'Doing course-improvements').

We also learned that the comic book helped the student to have a better understanding of the concepts described in the textbook, helping the students to fix the contents. In addition to that, it also brought humor to the class, reducing, therefore the stress the students were facing (Figure 2, Feedback loop 'Bringing humor to the classroom') and making learning more enjoyable. This finding is also aligned with the results of other researchers (Supriatna, Fauzi, & Holilah).

Figure 2. The course dynamics.

Limitations

In this case study the number of students was small (20). As this is qualitative research, we do not have the intention of generalizing the findings of the study. More than that, it is difficult to conclude that the learning that occurred in our course was only due to the application of the neuroscience concepts, as this was not a randomized controlled trial. The positive learning effects may have been due to other factors, such as the students' intrinsic motivation to learn as the students in this class could have been more motivated. We cannot exclude this possibility: however, based on the empirical data here presented, we may speculate that the utilization of the neuroscience concepts triggered the course's dynamics (the feedback loops we experienced in the program).

Another possible limitation is related to the evaluation of the long-lasting learning. We fostered, in many different ways (such as stimulating the students to connect the new concepts with the concepts they already know, by providing occasions on retrieval and reflection, by favoring metacognition processes and by challenging the students to study the class content previous to the class) the long-lasting learning. However, we may only speculate that the learning that occurred was long-lasting. In order to have more certainty about this issue we intend to accomplish another research, in a couple of years, with the same students, in order to verify if the long-lasting learning that we fostered in fact happened.

What could we have done differently?

Maybe we should have used a course platform with a better online forum that would allow better interaction between the students and the teacher. We may also speculate that, if we have given the students more complex projects and ask them to work in teams, they would have interacted more and learned even more. In an online learning context without Covid-19 pandemic, we certainly would follow that approach. However, with respect to the

students' stress and workload, we think that our choice was the most appropriate for the circumstances.

We hope that this case study can be helpful not only to PBL community but also for those interested in applying neuroscience concepts to their teaching and learning practices.

References

Arantes do Amaral, J. A., Hess, A., Gonçalves, P., & Rodrigues, V. P. (2017). Using Group Drawings Activities to Facilitate the Understanding of the Systemic Aspects of Projects. *International Journal of Instruction*, 10(2), 3-22.

Arantes do Amaral, J. A., Araujo, C. R. M., & dos Santos, R. J. R. L. (2018). Lessons Learned Implementing Project-based Learning in a Multi-campus Blended Learning Environment. *Journal of Problem Based Learning in Higher Education*, 6(2).

Arantes do Amaral, J. A., & Brito, S. C. (2018). Using the Arts to Foster Students' Interest, Engagement, and Learning in a Distance-Learning Environment. *Anatolian Journal of Education*, 3(2), 1-18.

Arantes do Amaral, J. A. (2019). Combining community-based learning and project-based learning: A qualitative systemic analysis of the experiences and perceptions of students and community partners. *Partnerships: a journal of service-learning and civic engagement*, 10(1), 129-145.

Bao, W. (2020). COVID-19 and online teaching in higher education: A case study of Peking University. *Human Behavior and Emerging Technologies, 2*(2), 113-115.

Beale, R., & Jackson, T. (1990). *Neural computing-an introduction*. New York, USA: CRC Press.

Bergmann, J., & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day*. Alexandria, USA: International Society for Technology in Education.

Bender, W. N. (2012). *Project-based learning: Differentiating instruction for the 21st century*. Thousand Oaks, USA: Corwin Press.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist, 26*(3-4), 369-398.

Bolton-Gary, C. (2012). Connecting through comics: Expanding opportunities for Teaching and Learning. *US-China Education Review, 4*(2012), 389-395.

Bradley, E. H., Curry, L. A., & Devers, K. J. (2007). Qualitative data analysis for health services research: developing taxonomy, themes, and theory. *Health Services Research, 42*(4), 1758-1772.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn*. Washington, USA: National Academy Press.

Cao, W., Fang, Z., Hou, G., Han, M., Xu, X., Dong, J., & Zheng, J. (2020). The psychological impact of the COVID-19 epidemic on college students in China. *Psychiatry Research*, 287, 1-5.

Christianson, S.A. (1992). Emotional stress and eyewitness memory: A critical review. *Psychological Bulletin, 112*(2), 284-309.

Deshler, D., Schumaker, J., Bulgren, J., Lenz, K., Jantzen, J.-E., Adams, G., . . . Marquis, J. (2001). Making learning easier: Connecting new knowledge to things students already know. *Teaching Exceptional Children, 33*(4), 82-85.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Changes in grey matter induced by training. *Nature, 427*(6972), 311-312.

El Miedany, Y. (2019). Flipped learning. In El Miedany Y. (Ed), *Rheumatology Teaching* (pp. 285-303). Kent, UK: Springer, Cham.

Fregni, F.(2019). *Critical thinking in teaching & learning: the nonintuitive new science of effective learning*. Boston, USA: Lumini LLC.

Fregni, F.,& Arantes do Amaral, J.A. (2020). *The cartoon guide to teaching and learning: a new way of learning the neuroscience of learning*. Monee, USA: Kindle Direct Publishing KDP.

Flumerfelt, S., & Green, G. (2013). Using lean in the flipped classroom for at risk students. *Journal of Educational Technology & Society*, *16*(1), 356-366.

Hebb, D. O. (1949). *The organization of behavior: a neuropsychological theory*. New York, USA: Wiley.

Hendry, G. D., Frommer, M., & Walker, R. A. (1999). Constructivism and problem-based learning. *Journal of further and higher education*, 23(3), 369-371.

Karpicke, J. D., Butler, A. C., & Roediger III, H. L. (2009). Metacognitive strategies in student learning: do students practise retrieval when they study on their own? *Memory, 17*(4), 471-479.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science, 319*(5865), 966-968.

Lalanda-Gonçalves, R. (2015). The qualitative systemic analysis in the context of qualitative research methods. *European Scientific Journal*, Special Edition, 25-31.

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project based learning*. Alexandria, USA: ASCD.

Larmer, J., & Mergendoller, J. R. (2010). Seven essentials for project-based learning. *Educational leadership, 68*(1), 34-37.

Markham, T. (2003). *Project based learning handbook: A guide to standards-focused project based learning for middle and high school teachers*. Novato,USA: Buck Institute for Education.

Morris, R. G., Kandel, E. R., & Squire, L. R. (1988). The neuroscience of learning and memory: cells, neural circuits and behavior. *Trends in Neurosciences, 11*(4), 125-127.

Nam, J. M. (2017). A Study between Online Entrepreneurship Education and Entrepreneurship: Based on PBL (Problem-Based Learning) and Flipped Learning. *Asia-Pacific Journal of Business Venturing and Entrepreneurship*, 12(2), 31-40.

Pollock, P. H., Hamann, K., & Wilson, B. M. (2011). Learning through discussions: Comparing the benefits of small-group and large-class settings. *Journal of Political Science Education, 7*(1), 48-64.

Reimers, F. M., & Schleicher, A. (2020). *A framework to guide an education response to the COVID-19 Pandemic of 2020*. Retrieved from https://learningportal.iiep.unesco.org/en/library/a-framework-to-guide-an-education-response-to-the-covid-19-pandemic-of-2020

Richardson, V. (2003). Constructivist pedagogy. *Teachers college record*, 105(9), 1623-1640.

Roehl, A., Reddy, S. L., & Shannon, G. J. (2013). The flipped classroom: An opportunity to engage millennial students through active learning strategies. *Journal of Family & Consumer Sciences*, 105(2), 44-49.

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational technology*, 35(5), 31-38.

Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. In Walker, A & Leary H(Eds). *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows*, (pp.5-15). Indiana, USA: Purdue University Press.

Savin-Baden, M., & Major, C. H. (2004). *Foundations of problem-based learning*. London, UK: McGraw-hill.

Schaffernicht, M. (2010). Causal loop diagrams between structure and behaviour: A critical analysis of the relationship between polarity, behaviour and events. *Systems Research and Behavioral Science, 27*(6), 653-666.

Senge, P. M., Cambron-McCabe, N., Lucas, T., Smith, B., & Dutton, J. (2012). *Schools that learn (updated and revised): A fifth discipline fieldbook for educators,*

parents, and everyone who cares about education. New York, USA: Crown Business.

Shiba, S., Graham, A., & Walden, D. (1993). *New American TQM*. Portland, USA: Productivity Press.

Siegle, D. (2014). Technology: Differentiating instruction by flipping the classroom. *Gifted Child Today*, *37*(1), 51-55.

Sousa, D. A. (2010). *Mind, brain, & education: Neuroscience implications for the classroom*. Bloomington, USA: Solution Tree Press.

Shih, W. L., & Tsai, C. Y. (2017). Students' perception of a flipped classroom approach to facilitating online project-based learning in marketing research courses. *Australasian Journal of Educational Technology*, *33*(5),32-49.

Smith, C. E. (2017). The flipped classroom: Benefits of student-led learning. *Nursing2019*, *47*(4), 20-22.

Sterman, J. (2010). *Business dynamics*. Boston, USA: Irwin/McGraw-Hill

Supriatna, N., Fauzi, W. I., & Holilah, M.(2019) Social studies comic: application of neuropedagogy approach to social studies text book of junior high school. *International Journal Pedagogy of Social Studies, 4*(2), 107-114.

Toquero, C. (2020). Challenges and opportunities for higher education amid the COVID-19 pandemic: The Philippine context. *Pedagogical Research, 5*(4), 1-5.

van Rooij, S. W. (2009). Scaffolding project-based learning with the project management body of knowledge (PMBOK®). *Computers & Education*, *52*(1), 210-219.

Weng, P. (2015). Developmental math, flipped and self-paced. *Primus*, 25(9-10), 768-781.

Yearworth, M., & White, L. (2013). The uses of qualitative data in multimethodology: Developing causal loop diagrams during the coding process. *European Journal of Operational Research, 231*(1), 151-161.

Zainuddin, Z., & Halili, S. H. (2016). Flipped classroom research and trends from different fields of study. *International Review of Research in Open and Distributed Learning, 17*(3), 313-340.

APPENDIX 1

Neuroscience concepts used and the respective course design changes

- *Neuroscience concept 1 - It is important to enhance neural network connectivity for long-lasting learning:* The teacher should stimulate the students to connect the new concepts with the concepts the students already know. The students were challenged to create videos, explaining how they have used (or intend to use) the concepts studied in the courses they teach. More than that, they were also required to participate in forum activities, making comments on other students' posts.

- *Neuroscience concept 2 - Retrieval leads to long-lasting learning*: In our program, students had to discuss the material after reading and thus discussing several points of view - also, the lecture (flipped classroom) was a retrieval of their previous learning. In addition, every week, they were required to answer questionnaires about the material they have studied that week. They were also required to watch the teacher's feedback video (that presents a recapitulation of the main points of the week).

- *Neuroscience concept 3 - Our attentional system filters out constant and repetitive information:* To foster learning, during our weekly meetings, the teacher never made use of long PowerPoint presentations. Instead of it, the weekly meetings were shorts: during the meetings the teacher always changed the type and the duration of the stimulus. For example, sometimes, the teacher asked the students to discuss one article. After that, he changed the focus of the discussion, inviting the students to reflect on a video or a comic strip. Sometimes the teacher asked for volunteers to answer a question; sometimes he chose the ones who would answer.

- *Neuroscience concept 4 -Moderate stress may be beneficial if related to the learning context:* The students were challenged to create short videos. As many of them didn't have this expertise, it brought moderate stress. However, the videos were related to the learning context.

- *Neuroscience concept 5 - Learning that is more applicable to the student context enhances learning efficiency:* We used images (such as comics and videos) to facilitate the students to understand abstract concepts and make connections with real-world situations. In our program, students watched videos of innovative teaching and learning programs, where teachers make use of PBL and neuroscience concepts in classroom activities. In addition to that, the students were challenged to read comics and discuss how the situations portraited were related to their practice as teacher.

APPENDIX 2

Week	Week Goals and Activities
01	*Week goals: to learn the basics concepts of project-based learning and the neural basis of learning.* *Readings:* Read the article: "Gold Standard PBL: Essential Project Design Elements" (Larmer, 2015) Read the chapters 01 of the textbook Read chapters 01 and 02 of the comic book. *Videos:* "Project-based learning: success start to finish" (Edutopia, 2012) *Online forum*: participate by posing a question, answer questions of other students or writing a reflection about what you have learned this week. *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 01: Individual reflection about the first week of the course
02	*Week goals: 1) to learn the basic principles of community-based learning 2) learn how our memory system works* *Readings:* Read the article: "Combining community-based learning and project-based learning: A qualitative systemic analysis of the experiences and perceptions of students and community partners" (Arantes do Amaral, 2019). Read the book's chapters 03 Read the comic book's chapter 03. *Videos:* "Community-based learning: what is it? How can I do it?" (Watnee, 2015), *Online forum*: participate by posing a question, answer questions of other students or writing a reflection about what you have learned this week. *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 02: Individual reflection about the first week of the course
03	*Week goals: 1) to learn the challenges of implementing PBL in blended learning environments 2) to learn the relationship between motivation and learning 3) to learn about online learning challenges and opportunities* *Readings:* Read the article: "Lessons Learned Implementing Project-based Learning in a Multi-campus Blended Learning Environment" (Arantes do Amaral et. al (2018)) Read the book's chapters 04 and 07 Read the comic book's chapters 04 and 07 *Movies:* Watch the movies: "A student-centered model of blended learning" (Edutopia,2019) "Teacher-created videos for remote learning" (Edutopia, 2020)

	Online forum: participate by posing a question, answer questions of other students or writing a reflection about what you have learned this week. *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 03: Individual reflection about the first week of the course
04	*Week goals: 1) Learn what is critical thinking and how to apply it in PBL centered courses* *Readings:* Read the book's chapter 08 Read the comic book's chapter 08 *Movies:* Watch the movies: "Critical thinking with Garfield Gini Newman" (Edmonton Regional Learning Consortium,2016) *Online forum*: participate by posing a question, answer questions of other students or writing a reflection about what you have learned this week. *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 04: Individual reflection about the first week of the course
05	Week goals: foster the development of long-lasting learning by reviewing the concepts studied making connections with student's teaching practice. *Project:* creation of a five-minutes video, making connection between one topic studied and the working experience of the student as teacher. *Readings:* there were no readings this week, however the students were challenged to review the topics studied in previous weeks Movies: the students were asked to watch the movies created by their peers. *Online forum*: participate by commenting about the videos created by other students. *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 05: Individual reflection about the first week of the course
06	*Week goals: 1) Learn how to use arts to foster learning in different PBL centered course contexts 2) Create a video, using art to explain a concept studied previously* *Project:* Create a short-video (approximately 5 minutes long) using one form of art to explain one topic studied in the previous week. *Readings:* Read the articles: "Using the Arts to Foster Students' Interest, Engagement, and Learning in a Distance-Learning Environment" (Arantes do Amaral & Brito, 2018) "Using Group Drawings Activities to Facilitate the Understanding of the Systemic Aspects of Projects" (Arantes do Amaral et. al.,2017) *Movies:* Watch the movie: "The powerful effects of drawing on learning" (Edutopia,2019)

	Movies: the students were asked to watch the movies created by their peers. *Online forum*: participate by commenting about the videos created by other students. *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 06: Individual reflection about the first week of the course
07	*Week goals: 1) Learn the different ways of grading a PBL centered course 2) Accomplish a self-evaluation* *Readings:* Read the book's chapter 09. Read the comic book's chapter 09 *Online meeting:* participate in debate, questioning or answering questions *Reflection about the week:* After the online meeting, answer the Questionnaire 06: Individual reflection about the first week of the course *Activity:* perform a self-evaluation

APPENDIX 3

Questionnaire

Question 01: Please let me know what you think worked in the course this week.

Question 02: Please let me know what you think didn't work in the course this week.

Question 03: What have you learned with the course activities of this week?

Question 04: Do you have any suggestions for the course's improvements?

APPENDIX 4

Course evaluation

Question 1: For all that we have studied in this course, what do you think can be useful for you to apply in the courses you teach?

Question 2: How did you like the weekly questionnaires (individual reflections)? (I would like to know if the questionnaires helped or not to your learning, and, if so, in which ways)

Question 3: How did you like the articles? (I would like to know if the articles helped or not to your learning, and, if so, in which ways)

Question 4: How did you like the videos? (I would like to know if the videos helped or not to your learning, and, if so, in which ways)

Question 5: How did you like the comic strips? (I would like to know if the comics helped or not to your learning, and, if so, in which ways)

Question 6: How did you like the experience of learning with your peers? (By means of participating in the online forums and by watching the videos they developed. I would like to know if the knowledge sharing helped or not to your learning, and, if so, in which ways)

Question 7: How did you like my weekly feedback? (I would like to know if my feedback helped or not to your learning, and, if so, in which ways)
Question 8: Which grade you would give yourself?
Question 9: Please justify the grade you would give yourself?
Question 10: Would you like to say something else, something that I didn't ask?